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VERTICAL ELECTRO-POLISHING COLLABORATION BETWEEN CORNELL, KEK, AND MARUI GALVANIZING CO. LTD.*

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Abstract

Cornell's SRF group, KEK, and Marui Galvanizing Co. Ltd (MGI) are collaborating since 2014 on Vertical Electro-Polishing (VEP) R&D as a part of a US/Japan Program for Cooperation in High Energy Physics. We have focused on an improvement of removal uniformity during the VEP process. MGI and KEK have developed their original VEP cathode named i-cathode Ninja®, which has four retractable wing-shape parts per cell. Cornell processed one single cell cavity with VEP using this cathode and performed a vertical test. KEK also provided one 9-cell cavity to Cornell. Cornell then performed surface treatments including Cornell VEP and RF test on this 9-cell cavity. The progress by the VEP collaboration and RF test results are presented in this paper.

INTRODUCTION

Cornell's SRF group has led the development of Vertical Electro-Polishing (VEP), which requires a much simpler setup and is less expensive compared with the conventional Horizontal EP [1]. After the successes of the Cornell VEP on the high gradient cavities for the ILC (>35MV/m with $Q>0.8\times10^{10}$) [2] and High-Q cavities for LCLS-II ($Q>2.7\times10^{10}$ at 16MV/m) [3], Cornell's VEP R&D focus has shifted to more advanced topics. One topic is a new EP cathode development in collaboration with KEK and Marui. The EP process in vertical direction can be affected by gravity, resulting in a removal difference between the upper and lower half cells. To compensate for removal un-uniformity, a cavity typically needs to be flipped over after half of the target removal. Marui has been developing a new cathode named "i-cathode Ninja" to improve the removal uniformity during its VEP R&D with KEK [4, 5]. Marui's work coincides with Cornell's interest in removal R&D, and collaboration between Cornell and KEK-Marui was started in 2014. As a part of this collaboration, KEK provided Cornell one brand-new 9-cell cavity, MHI-02, which was fabricated in house at KEK, for the future development of a 9-cell scale Ninja cathode. In this paper, we report the progress on these projects with detailed cavity test results.

NEW VEP CATHODE R&D AT CORNELL

Figure 1 shows a 1.3GHz TESLA shape single-cell cavity installed into Cornell VEP system with the Ninja-cathode. Two types of the Ninja cathode and top and bottom EP sleeves were shipped from Marui to Cornell. Cornell's VEP system was upgraded to allow for acid circulation during the VEP process with the Ninja cathode.

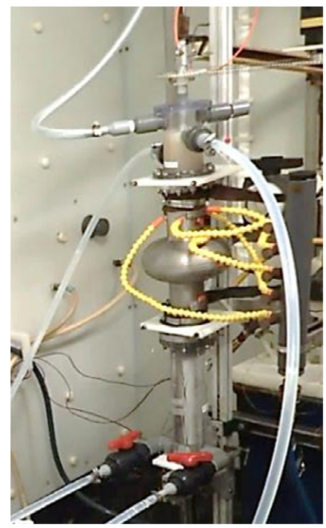

Figure 1: Cornell VEP system with the Ninja cathode.

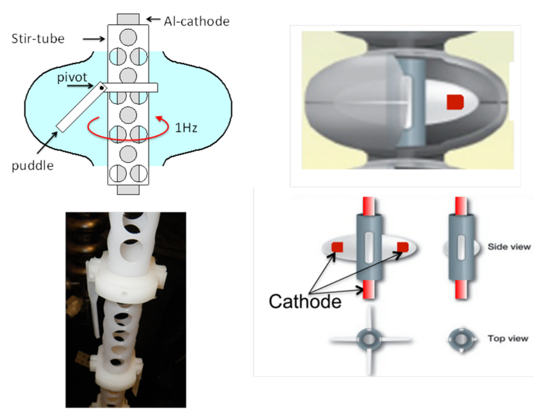

Figure 2: Images of Cornell VEP cathode (left); Marui's i-cathode Ninja type-I (right).

Cornell's and Marui's VEP Cathodes

Cornell VEP cathode (Fig. 2, left) consists out of an aluminium rod and a stirring tube with paddles (one paddle per cell). Teflon mesh lapped around the stirring tube (not shown in the figure) guides the hydrogen bubbles produced on the cathode during the EP process to prevent them from attacking the niobium surface. Marui's Ninja cathode (Fig. 2, right) consists out of an aluminium cathode rod, polyvinyl chloride (PVC) tube, and retractable Teflon wings (four wings per cell). PVC is an acid resistance material, and inexpensive. It is therefore suitable

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Table 1: VEP Parameters

		Cornell cathode	Ninja type-I	Ninja type-II
Voltage [volt]		14	14	14
Current [amps]		~17	~22	~29
Temp. (cavity outside) [degC]		17~18	20~25	20~25
Acid circulation [L/min.]		None	5	5
Agitation speed [Hz]		0~1	0.8	0.8
Puddle type /cell		1Teflon paddle	4 Teflon wings w/ Al	4 Teflon wings
Teflon cathode bag		Yes	None	Yes
Removal [µm] (preliminary)	Target	20	20	20
	Top half cell	24	36	29
	Bottom half	14	20	18

for the early stage of the Ninja cathode development and for capital cost reduction of VEP. The retractable wings are kept inside the PVC tube during the installation, and are then opened when inside the cell. The gap between the wing edge and the cell surface is designed to be equal from iris to equator. Marui has developed several types of the Ninja cathode so far. The type-I and type-II Ninja cathodes were used for the first trial at Cornell [6]. The type-I is designed for having field uniformly from iris to equator by putting an Al coupon on top of each wing (Fig. 2). The type-II has no Al coupon on the wings, but has more cathode surface area inside the tube. The type-II is also designed to protect the Nb surface from hydrogen bubbles by covering the opening between the wings and the tube with Teflon mesh.

Ninja Cathode VEP at Cornell

A 1.3GHz TESLA shape single cell cavity (NR1-2) was processed with the Ninja cathode in the Cornell VEP system. NR1-2 had been processed by VEP using the Cornell cathode and tested already. To reset the RF surface prior to the Ninja cathode VEP, NR1-2 had mechanical polishing (30µm), Buffered Chemical Polishing (BCP, 60µm), and furnace degassing (800degC, 2hrs). Cornell then performed two VEPs (20µm each) using the Ninja cathodes of type-I and type-II, followed by low-temperature baking (120degC for 48hrs) and RF test. A HF based EP electrolyte was used for all VEPs on NR1-2, which is an acid mixture of sulphuric acid and hydrofluoric acid in 9~10:1 ratio in volume. Detail parameters of these VEPs are summarized in Table 1. High removal uniformity post the Ninja cathode VEP was not yet expected, since these were the first VEPs with the Ninja cathode at Cornell. The parameters of the Ninja cathodes in Table 1 were optimized for the Marui's VEP system, but not for the Cornell's system. A parametric study with the Ninja cathode and the Cornell VEP system will be necessary for further process optimization. Optical inspections were done after each VEP process on NR1-2 (Fig. 3). Similar defects or features were seen on both surfaces after Cornell and Ninja VEP.

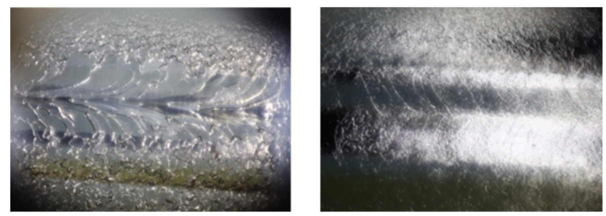

Figure 3: Optical inspection images of the equator weld seam on the RF surface; Cornell VEP (left), Ninja cathode type-I (right).

Cavity RF Test

Figure 4 shows the RF test results of NR1-2 as the quality factor of Q_0 versus the accelerator field gradient of E_{acc} at 2K. The blue circles show the test result after the Cornell cathode VEP. The cavity quenched at 33MV/m with Q_0 of 1.2×10^{10} without field emission. The red triangles show the result after the Ninja cathode VEP. The quench field was 35MV/m with Q_0 of 0.9×10^{10} without field emission. Thus, the Ninja cathode provided a good cavity RF performance comparable with the Cornell cathode.

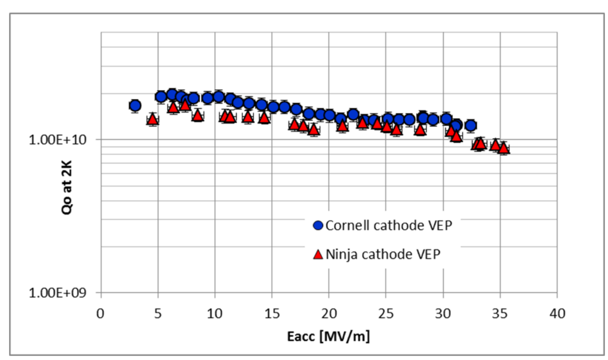

Figure 4: RF test results of NR1-2 at 2K.

R&D ON KEK 9-CELL AT CORNELL

As a part of US-Japan collaboration program, a new 9-cell cavity, MHI-02, has been loaned to Cornell from KEK. The overall plan is for Cornell to perform a baseline RF test on MHI-02 after applying Cornell's VEP, and then, once Marui has completed a 9-cell scale Ninja cathode, Cornell will perform a 9-cell scale Ninja cathode

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VEP and evaluate the cathode and cavity performances. In the early stage of this R&D on MHI-02, the cavity was shipped back and forth between Cornell and KEK to have surface treatments. Table 2 shows a summary of surface treatments on MHI-02 completed so far. Figure 5 shows images of the 9-cell cavity surface treatments at Cornell.

Table 2: Summary of Completed Surface Treatments on MHI-02

	Surface Treatments
KEK	Cavity fabrication
Cornell	Bulk BCP (120µm, Fig. 5 left)
	800degC degassing
KEK	Optical inspection
	Local grinding
	Frequency flatness tuning
Cornell	Std. Cornell VEP (40µm, Fig. 5 right)

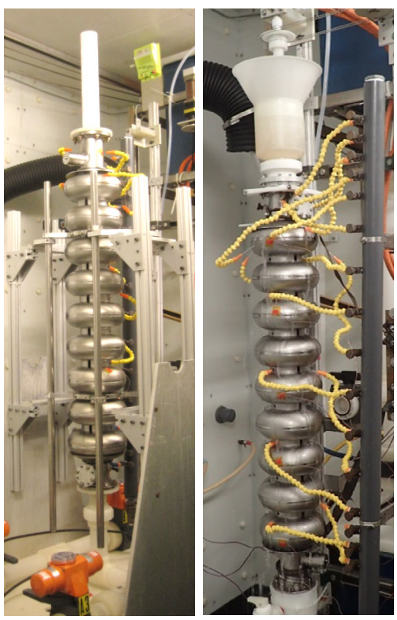

Figure 5: MHI-02 on BCP stand (left) and on VEP stand (right) at Cornell.

Low Temperature Nitrogen Baking on 9-cell at Cornell

As one recent focus of the high-Q R&D at Cornell, we have investigated the nitrogen bake of a SRF cavity in the low temperature regime ($T \leq 200$degC) [7] based on previous work at Fermilab [8] where nitride formation is not an issue and post-treatment chemistry is not needed. So far, a single cell cavity and niobium coupons have received the low temperature nitrogen baking. RF test and surface analysis have been performed on them [7, 9]. We now have applied the low-temperature baking on MHI-02 as the first attempt on a multi-cell cavity. The parameters are summarized in Table 3. Figure 6 shows the profiles of temperature and nitrogen pressure and Figure 7 shows MHI-02 in the TM furnace.

Table 3: Parameters of Low Temperature Nitrogen Baking on MHI-02

1)	800degC x 10hrs in vacuum
2)	160degC x 48hrs in N_2, ~35mTorr
3)	160degC x 48hrs in vacuum

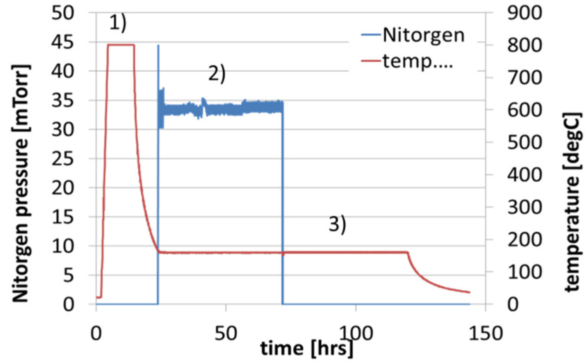

Figure 6: The low temperature baking profile.

Figure 7: MHI-02 in the TM furnace.

RF Test Results Post the Low Temp. Baking

Figure 8 shows the RF test results of MHI-02 post the low temperature baking in nitrogen atmosphere as Q_0 vs. E_{acc} at 1.58K to 2K. The characteristic anti-Q-slope profile is seen at fields up to 15MV/m. Q-slope starting from 15MV/m limited the cavity performance. The cavity quenched at 23MV/m with Q_0 of $0.9\text{x}10^{10}$ at 2K. No detectable field emission observed during the test.

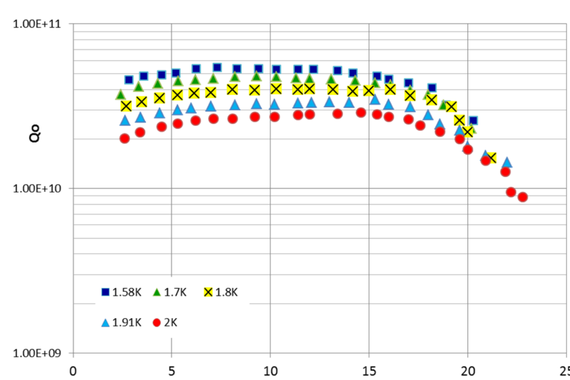

Figure 8: 9-cell RF test results post the low temperature baking in nitrogen atmosphere.

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SUMMARY

Vertical EP with the new Ninja cathode was demonstrated on a single-cell cavity at Cornell. RF performance was good and comparable with that using the Cornell cathode. A parametric study will be necessary to optimize removal uniformity. The development of a 9-cell scale Ninja cathode is in progress at Marui.

The first attempt of low temperature baking in N_2 on a 9-cell cavity successfully shows an anti-Q-slope. Various recipe and parametric studies on low temperature baking are in progress using Nb coupons and single cell cavities. Based on feedback from coupon studies, MHI-02 will be processed again with an optimized low temperature baking, and again tested in the future.

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